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RESEARCH MEMORANDUM

TANK INVESTIGATION OF THE GRUMMAN JRF-5 AIRPLANE FITTED WITH HYDRO-SKIS SUITABLE FOR OPERATION ON WATER, SNOW, AND ICE

By Kenneth L. Wadlin and John A. Ramsen

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Results are presented from a tank investigation of a $\frac{1}{8}$-size powered dynamic model of the Grumman JRF-5 airplane fitted with tandem hydro-skis and auxiliary wing-tip skids suitable for operation on water, snow, and ice. Take-off stability and control of the airplane would be adequate for water operation with this arrangement. Water take-offs would be possible with the available thrust. Landing behavior in smooth water would be satisfactory with yaw up to 15°. Motions and accelerations during landings in rough seas would be much less than those for the airplane without skis. Accelerations in 7-foot waves would be less than those for the airplane without skis in 4-foot waves.

INTRODUCTION

As part of a research program to arrive at means of providing acceptable take-off and landing characteristics for high-speed water-based aircraft without impairment of flight performance, the National Advisory Committee for Aeronautics has been conducting an investigation into the use of a retractable landing gear consisting of planing surfaces called hydro-skis. (See reference 1.) Hydro-skis were proposed to the U.S. Air Force by the Edo Corporation as a means of operating a high-performance fighter from snow and ice as well as water.

In order to evaluate the possibilities and problems involved in operating from these surfaces, Edo Corporation undertook a project to install suitable hydro-skis on a Grumman JRF-5 amphibian for full-scale tests of such a landing gear. In order to obtain good maneuverability for snow and ice operation, the arrangement selected was a

main hydro-ski near the center of gravity with a controllable tail ski in tandem and with wing-tip skids to give lateral support. At the request of the Air Force, extensive development tests were made in the Langley tank no. 2 to aid the contractor in evaluating the effect on the hydrodynamic characteristics of various design parameters involved and to evaluate the final configuration chosen. The airplane was subsequently modified to this configuration and successfully flown by Edo Corporation from water, snow, ice, and, to a limited extent, from sod-covered areas.

The tank program was not primarily intended to provide data of a fundamental or systematic nature on hydro-skis but to arrive at a hydrodynamically acceptable configuration for the Grumman JRF-5 in the shortest possible time. The scope of this paper is, therefore, confined to the results obtained with the final configuration which was actually built and flown.

DESCRIPTION OF MODEL

A $\frac{1}{8}$-size powered dynamic model of the Grumman JRF-5 was constructed at the Langley Aeronautical Laboratory for the tank investigation. The general arrangement of the model with the final hydro-ski and skid configuration is shown in figure 1. Photographs of the model are shown as figure 2.

The model had scale-diameter two-blade propellers driven by direct-current electric motors. It also had movable control surfaces of scale dimensions. Slats were installed on the leading edge of the wing to obtain approximately scale aerodynamic lift characteristics.

The lines of the main ski and tail ski are shown in figures 3 and 4, respectively. These lines were evolved by the contractor largely through requirements for snow and ice operation. The tapered plan form and the ski area were based primarily on the results of the tests of reference 1.

The location and details of the wing-tip skids are shown in figure 5. The pivot points shown in the drawings of the skis and skids are for use in snow and ice operation only and are included herein merely to provide a convenient reference for location of the struts.

The skis were attached rigidly to the hull by faired struts. The skids were also attached by faired struts with the position of the skids being fixed except when the effect of castering the skids was investigated. Details of the struts are shown in figure 6.

APPARATUS AND PROCEDURE

Take-Off Tests

General.- The test setup with the model floating at normal gross weight (8000 lb, full size) is shown in figure 7. The model was free to trim about the center of gravity and free to rise but was restrained in yaw. It was also restrained in roll except when stability in roll was investigated.

The elevators were varied over a range of deflections from -30° to 5°. A flap deflection of 30° was used for all tests. For the tests to determine the effect of varying this parameter 0° and 60° flaps were also included.

Longitudinal stability.- To find the trim limits of stability the model was towed from the normal center of gravity ($0.226\bar{c}$, where $\bar{c}$ is the mean aerodynamic chord) at constant speeds with full power (3750 lb thrust, full size). The trim, defined as the angle between the undisturbed water surface and the hull forebody keel, was slowly increased or decreased by use of the elevators until porpoising began or maximum elevator deflection was reached.

The variation of trim with speed for several locations of the center of gravity and several elevator settings was determined during runs at an acceleration of 1.0 foot per second per second and with full power. The range of available center-of-gravity and elevator positions which would permit take-off without porposing was determined from these runs. The variation of trim with speed for three flap deflections at the normal center-of-gravity position was also determined in this manner.

Resistance.- The resistance as determined in these tests is defined by the equation

$$R = T_e - T_x$$

where

R total resistance, pounds

T_e effective thrust, pounds

T_x resultant horizontal force with power on and the model in the water, pounds

The effective thrust T_e is defined by the equation

$$T_e = D_c + R_H$$

where

D_c air drag of the model with propellers fixed, pounds

R_H resultant horizontal aerodynamic force with power on, pounds

These values (D_c and R_H) were determined at various speeds with the model just clear of the water at 0° trim and with the flaps set at 30° and the elevators at 0°. The excess thrust was determined from constant speed runs with the model in the water fixed in trim. The range of trims tested at each speed corresponded to the range of stable trims found in the stability tests.

Partial power corresponding to 62.5 percent static thrust (2340 lb thrust, full size) was the highest which could be used during constant speed runs without an appreciable thrust drop due to overheating the electric motors in the model. This thrust was therefore used for all the resistance tests.

Landing Tests

General.- Landing tests were made with the model balanced about the normal center of gravity ($0.226\bar{c}$) and the elevators set to maintain the desired trim while in the air. The data were recorded by means of motion pictures, accelerometer records, and visual observations.

Smooth water.- For the smooth-water landings, the model was launched as a free body from the Langley tank no. 2 monorail. Both straight and yawed landings were made with the normal configuration and with the wing-tip skids incorporating a castering arrangement.

Rough water.- For the rough-water landings, the model was launched as a free body from the towing carriage into oncoming waves generated by the Langley tank no. 2 wave maker. Wave heights of 4 to 7 feet (full size) were used with wave lengths varying from 40 to 240 feet (full size).

RESULTS AND DISCUSSION

Take-Off Tests

General behavior.- Sequence photographs of a typical take-off run with the model free to roll are shown in figure 8. In this condition, the torque of the propellers tended to roll the model onto the left skid. Right aileron deflection of 10° was applied which caused the model to roll onto the right skid at planing speeds. This deflection was less than the amount available and thus indicated that the airplane would be laterally controllable in a smooth-water, no-wind condition.

As can be seen from the photographs, the model rose onto the skis at a speed corresponding to between 20 and 30 miles per hour (full size) with both skids clear. As the speed increased, the deflected ailerons took effect and rolled the model until it was supported by the right skid.

The rise of the model with skis was greater than that of the hull alone at all speeds due to the lift provided by the skis. This increase in rise had a beneficial effect at the lower speeds in that it reduced the amount of spray thrown on the windshield and into the propellers.

During the take-off tests, the skis tended to emerge due to upper-surface lift at too low a speed to provide sufficient planing lift for sustentation. This tendency to lose lift resulted in a vertical instability over a small speed range. The emergence instability was overcome by increasing the acceleration. It was also believed (and subsequently demonstrated full scale) that it could be avoided by pilot control, that is, reducing the trim and delaying emergence until the minimum speed necessary for planing was reached.

Longitudinal stability.- The trim limits of stability are presented in figure 9 which also indicates the extent of the emergence instability at constant speeds. The lower limit below which porpoising was encountered occurred at rather high trims just after emergence but quickly dropped to low trims as the speed was increased. The upper-limit porpoising was mild and no lower branch of the upper limit was obtained.

Trim tracks for various elevator and flap deflections at the normal center of gravity are shown in figure 10. All of the trim curves had a small range of speeds between 20 and 30 miles per hour where no stable points could be obtained at the acceleration used due to emergence instability. The extent of this range of speeds varied from 4 to 6 miles per hour. Increasing the flap deflection or elevator deflection generally shifted the range to slightly lower speeds.

Increasing the flap deflection tended to decrease the trims and to decrease the take-off speed for a given trim. Both effects were much more noticeable between 0° and 30° flaps than between 30° and 60° flaps. The stable elevator range remained the same for 30° and 60° flaps (-10° to -22.5°). For 0° flaps the stable elevator range decreased to from -5° to -15°.

With the elevators set at 0° and with 30° or 60° flaps, the model began lower-limit porpoising immediately after emergence. At a flap setting of 0°, it achieved a steady trim and then began lower-limit porpoising at a slightly higher speed.

The center-of-gravity limits of stability are presented in figure 11. Since these limits were obtained from tests at a low acceleration (1.0 ft/sec^2), emergence instability occurred. This instability was not considered in plotting the limits. At the normal center of gravity ($0.226\bar{c}$) there was an elevator range of 12.5° for which no porpoising occurred. Previous test experience indicates that this range would be increased at higher accelerations.

Resistance.- Curves of total resistance, trim, and rise of the model, with and without skis, converted to full-size values are shown in figure 12. The total resistance includes both the water resistance and the air drag of the model and is the envelope of minimum resistance from fixed trim tests over the stable range of trims. A curve showing the estimated available trust is included which indicates that there would be considerable excess thrust at all speeds.

The resistance and corresponding trim for the model without skis is less than that for the model with skis except at the higher speeds near take-off.

A probable trim track and the total resistance for a take-off with skis at a take-off trim of 8° is also included in figure 12. The resistance at these trims at the higher speeds remained lower than for the model without skis. The resistance of the model with skis is less at these speeds due to the more favorable planing characteristics of the skis and the absence of afterbody wetting.

Landing Tests

Smooth water.- Sequence photographs of a typical smooth-water landing at 8° trim are presented in figure 13. The model maintained essentially a constant trim with the tail ski clear for the greater part of the run. Just before submergence an increase in trim took place and the tail ski entered the water. At this point the model trimmed down and the main ski submerged so that the model came to rest on the hull.

The maximum normal accelerations encountered during the smooth-water landings increased with increasing landing trim from a value too small to read from the accelerometer records at 4° to 0.5g at 8° and to 0.9g at 12°. The model was very stable on landing and tended to seek the same running trim regardless of its original landing trim.

Smooth-water landing tests made with the model yawed to the left indicated that yaw angles up to a value of 15° had no serious effects on landing behavior. With all yaw settings the path remained straight while the yaw angle tended to decrease to zero. This decrease in yaw angle was accompanied by rolling to the right. The normal accelerations encountered in the yaw tests were about the same as those encountered in smooth-water landings at the same trims.

Castering of the wing-tip skids proved to have a negligible effect on both straight and yawed landings. The skids appeared to aline themselves with the path of the model.

Rough water.- In the rough-water landings, the model without skis hit the waves with very little penetration and skipped off violently with large changes in both trim and rise. When the model with skis hit the waves, the skis penetrated somewhat while following the wave contour. The motions were similar in character but their magnitudes were much smaller for the model with skis than for the model without skis. Sequence photographs of a typical rough-water landing for the model with skis in waves corresponding to 4 feet high and 120 feet long (full size) are shown in figure 14.

Maximum normal accelerations encountered at various wave lengths for the model with skis in waves corresponding to 4 feet and 7 feet high (full size) and the model without skis in waves corresponding to 4 feet high (full size) are shown in figure 15. Each point represents the maximum normal acceleration for one run regardless of the contact at which this occurred. Generally, the maximum acceleration did not occur at the first contact. Since the only control applied was that necessary to maintain trim while in the air, the position on the wave at which initial contact was made was not under control. This caused variations in the ensuing behavior which led to variations in the maximum acceleration encountered even when the wave length and initial landing trim were held constant.

The envelopes of the data represent the maximum accelerations that were obtained over the range of wave lengths tested. The maximum acceleration obtained with the skis in 4-foot waves (3.2g) is only 60 percent of that obtained with the hull alone (5.5g) in the same height waves. In 7-foot waves the maximum acceleration with skis was 4.2g which is still less than 80 percent of that obtained with the hull alone in 4-foot waves. It was not considered advisable to run

the model without the skis in the higher waves due to the already excessive accelerations and motions obtained in the 4-foot waves.

Time-history records of normal accelerations for the first part of the runs which gave the greatest acceleration at the three conditions tested are shown in figure 16.

CONCLUSIONS

From a consideration of the data obtained from tank tests of a $\frac{1}{8}$-size model it was concluded that for the Grumman JRF-5 airplane fitted with tandem hydro-skis and auxiliary wing-tip skids:

1. The take-off stability and control would be adequate for water operation.

2. Water take-offs would be possible with the available thrust.

3. The landing behavior in smooth water would be satisfactory for all initial trims and for initial angles of yaw up to 15°. Castering of the tip skids would have a negligible effect on water operation.

4. The motions and accelerations during landing in rough seas would be much less than those for the airplane without skis. The accelerations in 7-foot waves would be less than those for the airplane without skis in 4-foot waves.

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National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCE

1. Dawson, John R., and Wadlin, Kenneth L.: Preliminary Tank Tests of NACA Hydro-Skis for High-Speed Airplanes. NACA RM L7I04, 1947.

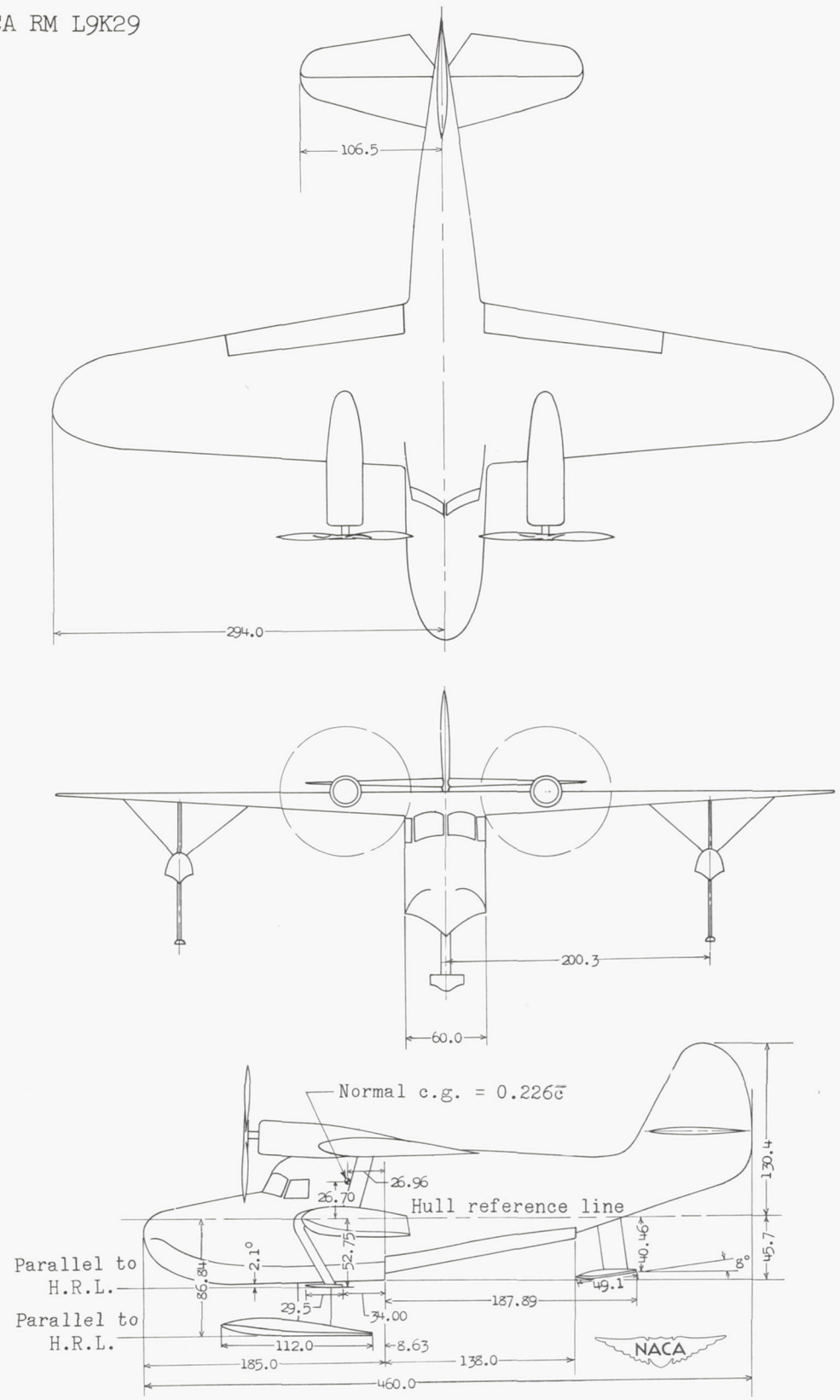


Figure 1.- General arrangement of $\frac{1}{8}$-size model of Grumman JRF-5 airplane fitted with hydro-skis. (Dimensions are in inches, full size.)

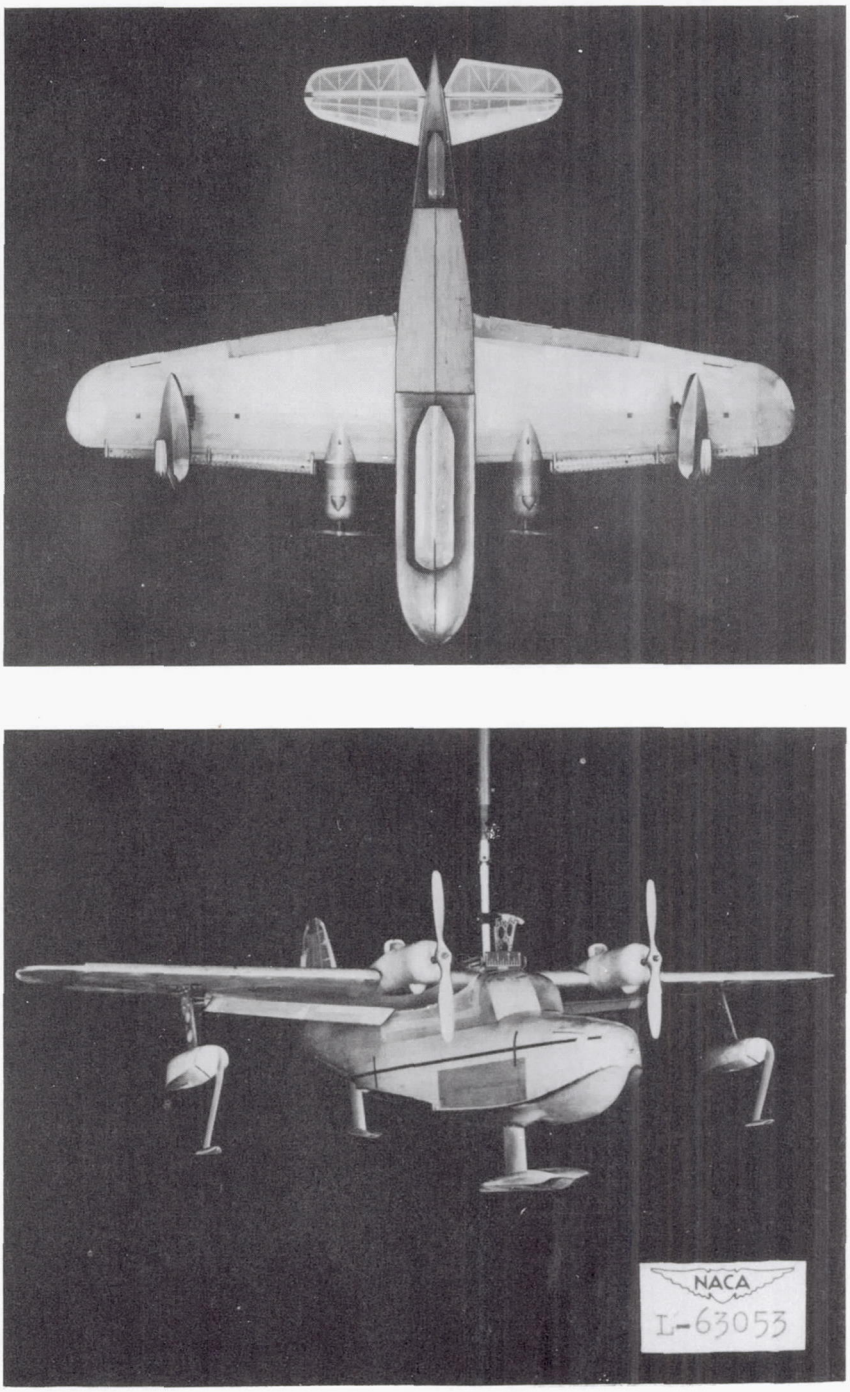
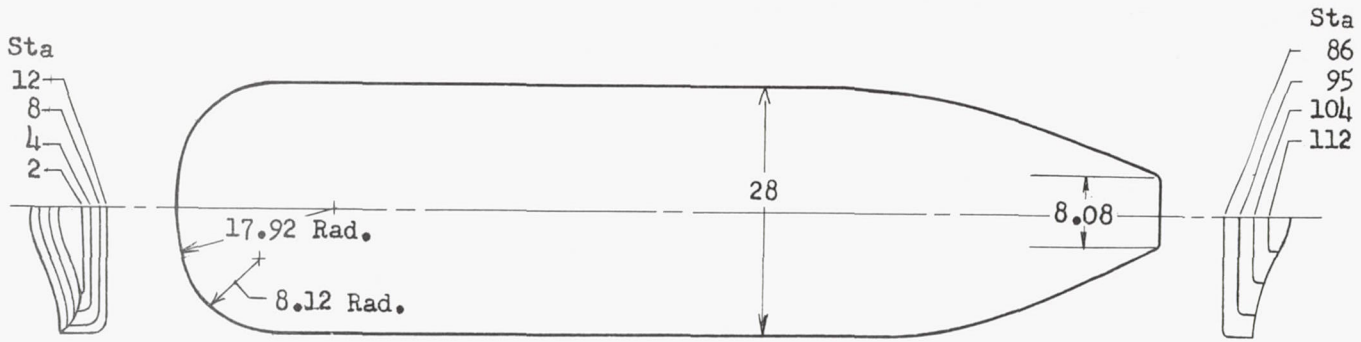
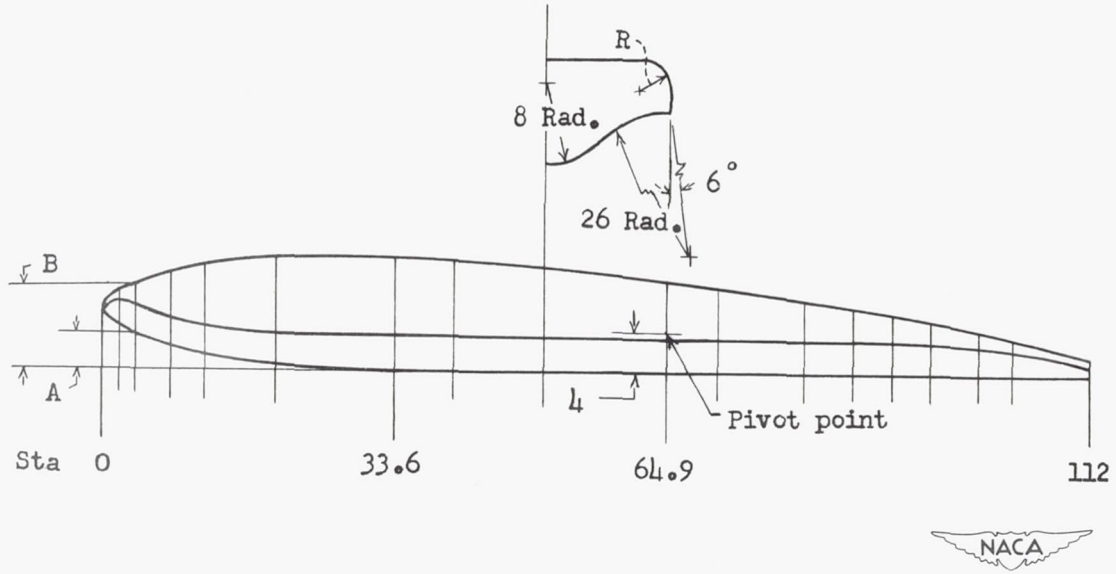


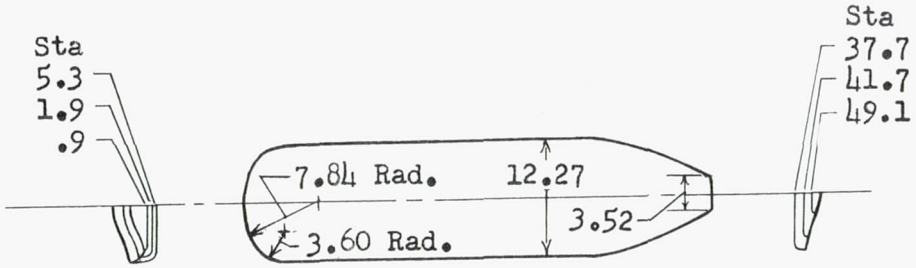
Figure 2.- $\frac{1}{8}$-size powered dynamic model of Grumman JRF-5 airplane fitted with hydro-skis.

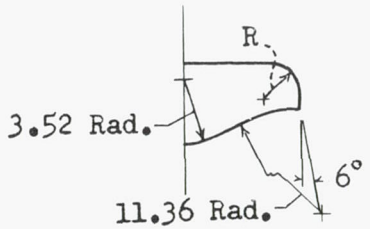




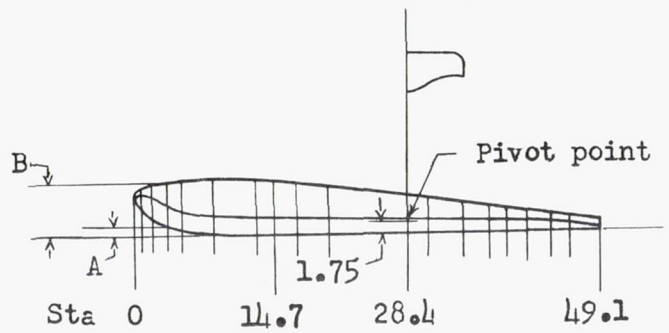
Main Ski Offset Table			
Sta	R	A	B
0	-	7	7
2	.62	5.12	8.68
4	1.75	3.96	9.46
8	2	2.44	10.52
12		1.44	11.36
20		.40	12.50
33.6		0	12.96
40			12.86
50			12.24
64.9			10.80
70			10.18
80			8.60
86			7.65
90			6.88
95	2		5.90
100	1.38		4.84
104	1		3.85
112	1	0	2.00

Figure 3.- Lines of main ski. (Dimensions are in inches, full size.)



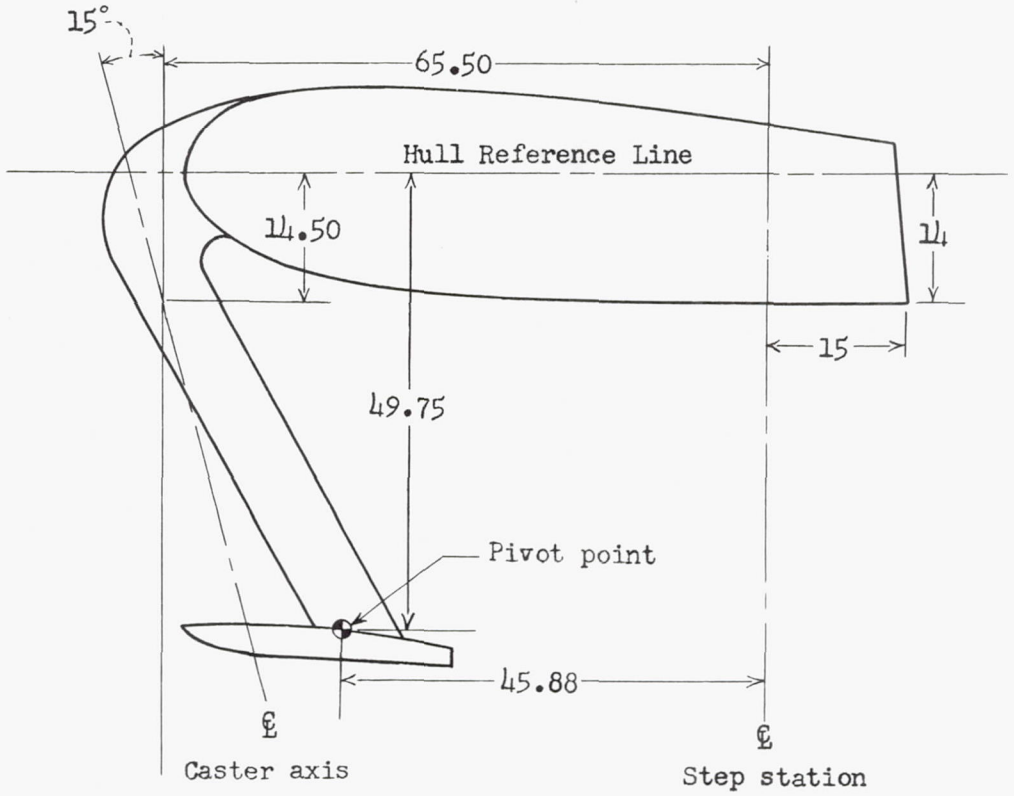


Half section at station 28.4



Tail Ski Offset Table			
Sta	R	A	B
0	-	4.24	4.24
.9	.40	3.04	4.96
1.9	1.20	2.16	5.20
3.5	2.00	1.36	5.44
5.3	2.16	.80	5.6
8.8	↑	.24	5.76
13.1	↓	.08	5.76
14.7	↓	0	-
17.5	↓	↑	5.6
21.9	↓	↓	5.36
28.4	↓	↓	4.72
30.7	2.16	↓	4.4
35.0	1.92	↓	3.76
37.7	1.52	↓	3.28
39.4	-	↓	2.96
41.7	.72	↓	2.56
43.9	-	↓	2.08
45.6	.32	↓	-
49.1	.32	0	.88

Figure 4.- Lines of tail ski. (Dimensions are in inches, full size.)



Sta	0.00	0.50	2.50	5.50	7.25	12.50	17.63	19.25	22.50	29.50
A	3.00	2.17	.74	.08	0.00	0.00	0.00	0.00	0.00	0.00
B	3.00	-	3.49	3.62	3.62	3.44	2.97	-	2.32	1.00
C	0.00	-	-	-	4.00	4.00	4.00	4.00	3.88	2.75
R_1	-	-	3.10	4.00	4.30	4.48	5.03	-	5.90	6.86
R_2	-	-	2.62	3.38	3.38	3.10	2.48	-	1.73	0.62

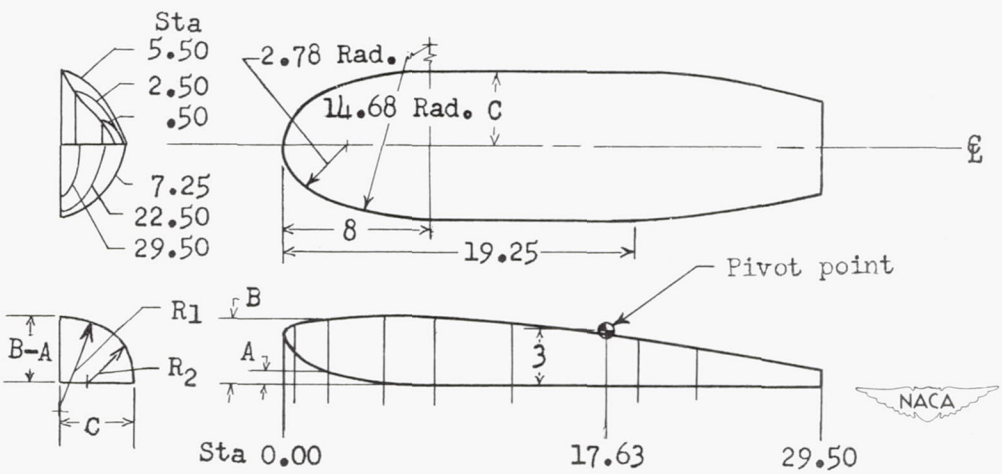
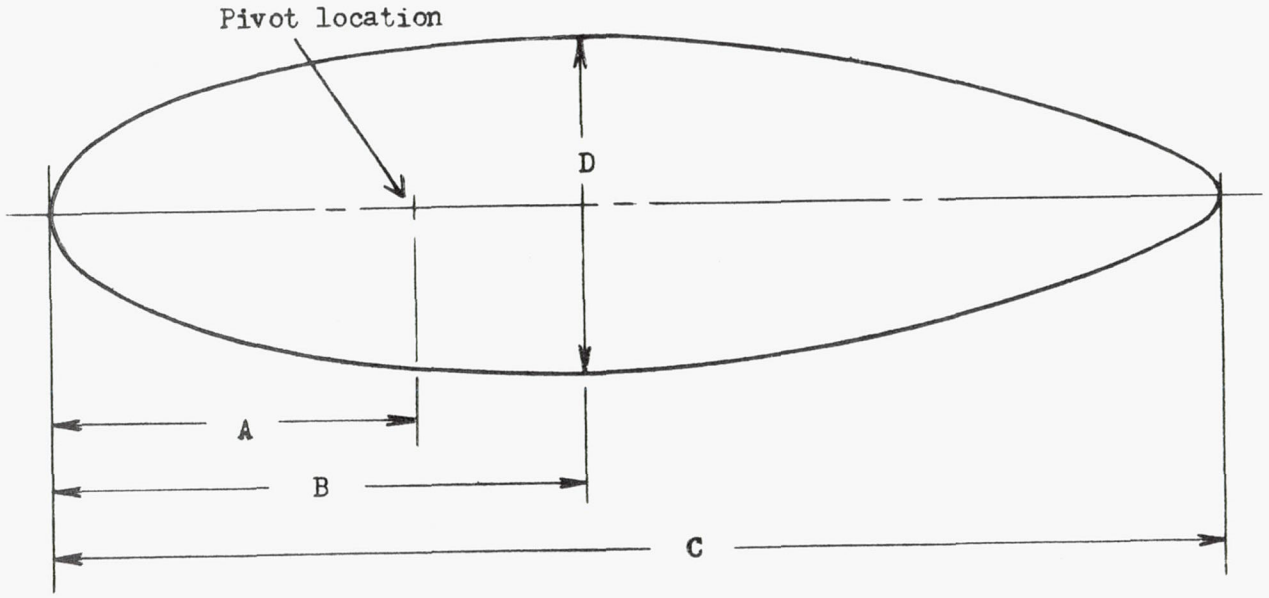


Figure 5.- Location and details of wing-tip skids. (Dimensions are in inches, full size.)



	Distance from nose to pivot location A	Distance from nose to maximum thickness B	Overall length C	Maximum thickness D
Main ski	7.625	10.68	24.50	7.00
Tail ski	6.625	8.39	19.25	5.50
Tip skid	2.500	3.36	7.70	2.20

Figure 6.- Strut details. (Dimensions are in inches, full size.)

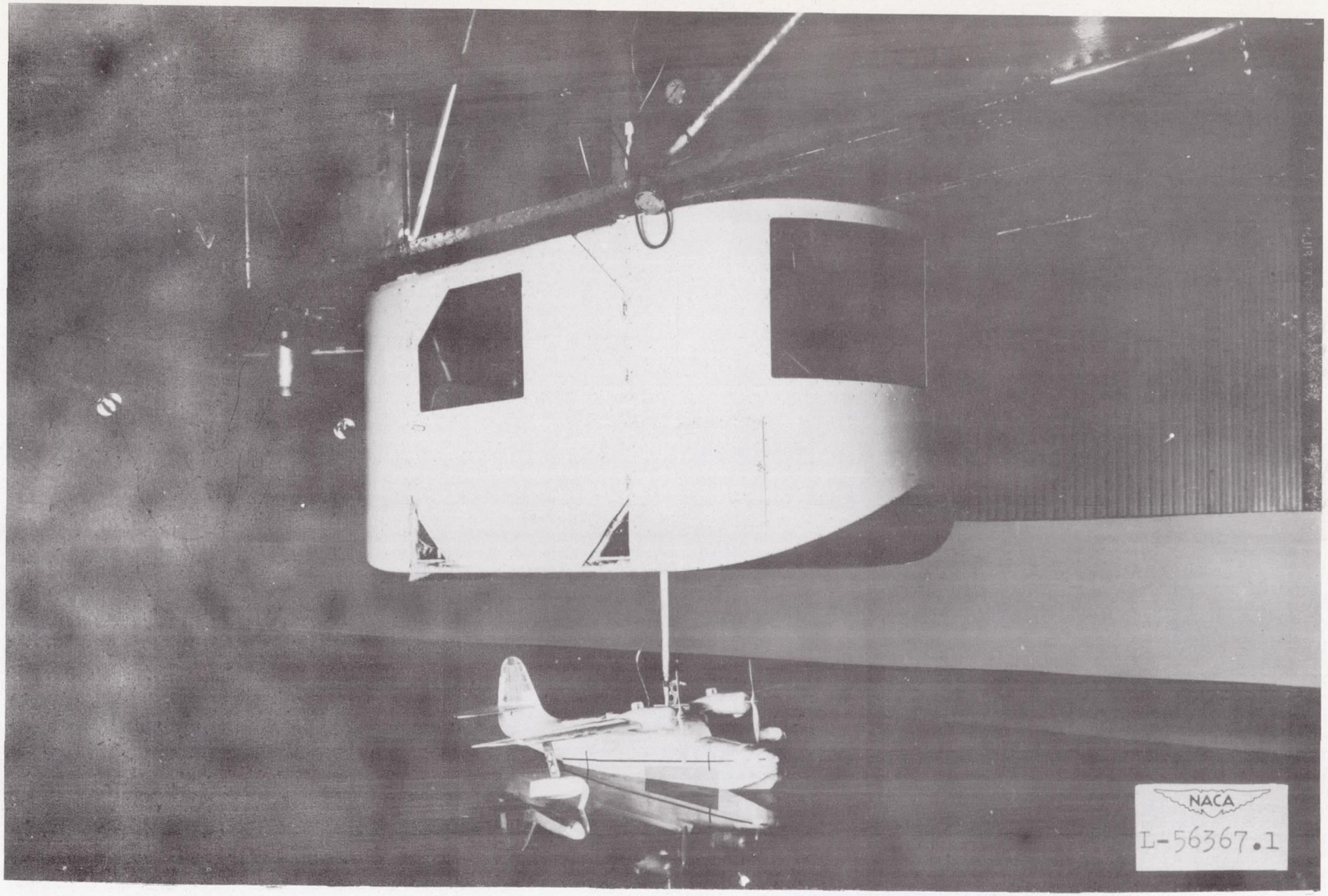
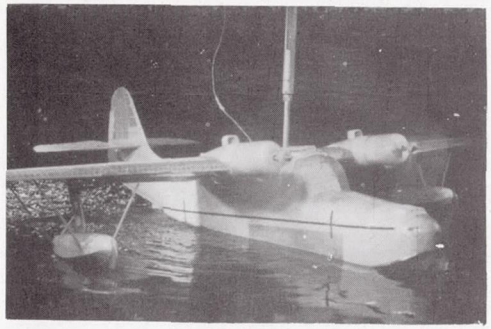
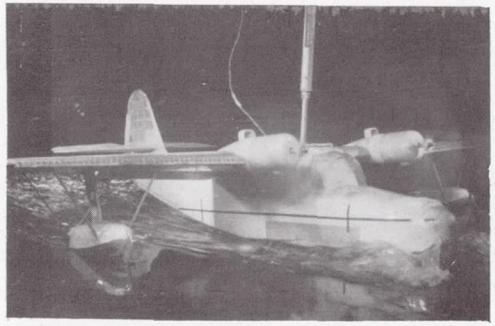


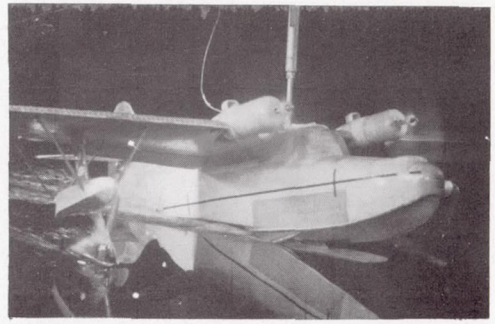
Figure 7.- Test setup showing model floating at normal gross weight.



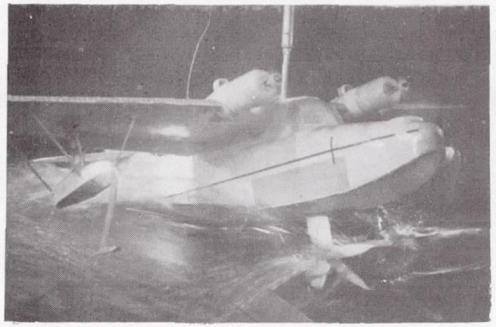
At rest



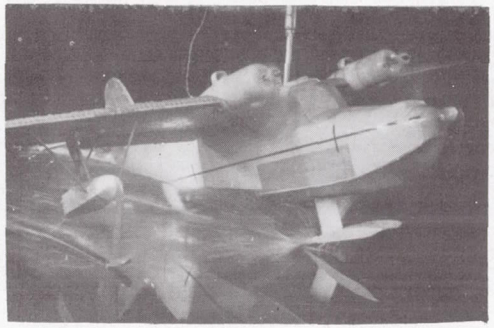
10 mph



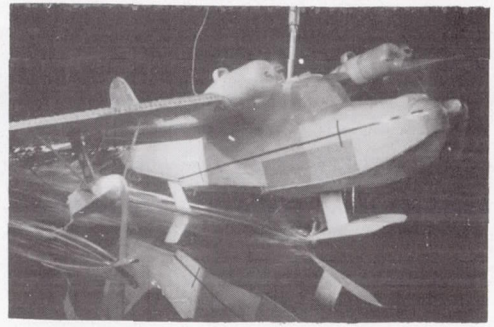
20 mph



30 mph



50 mph



60 mph

Figure 8.- Sequence photographs of a typical take-off run with the model free to roll; 10° right aileron applied. (Speeds are full size.)

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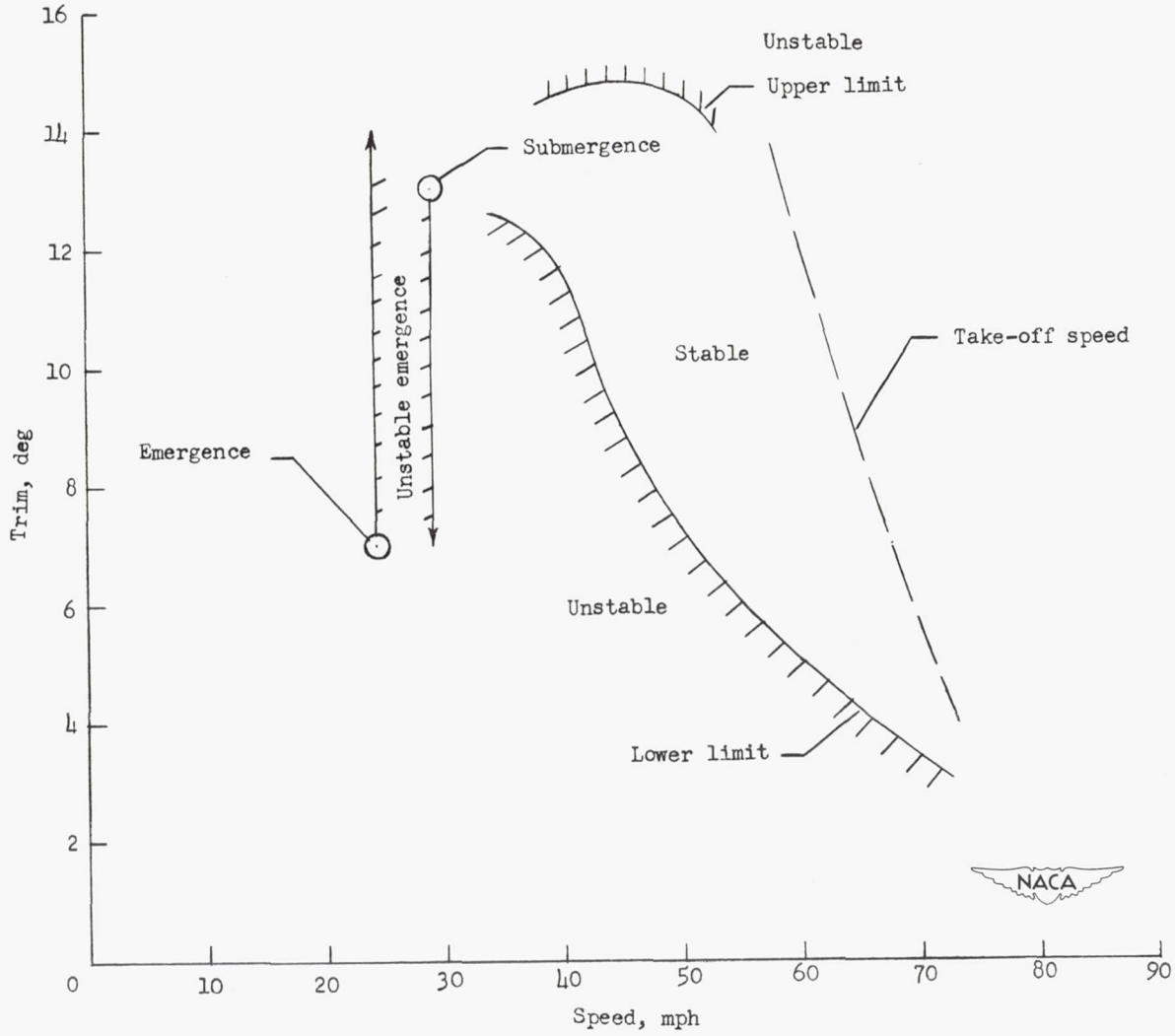


Figure 9.- Trim limits of stability for the Grumman JRF-5 with hydro-skis. (Values are full size.)

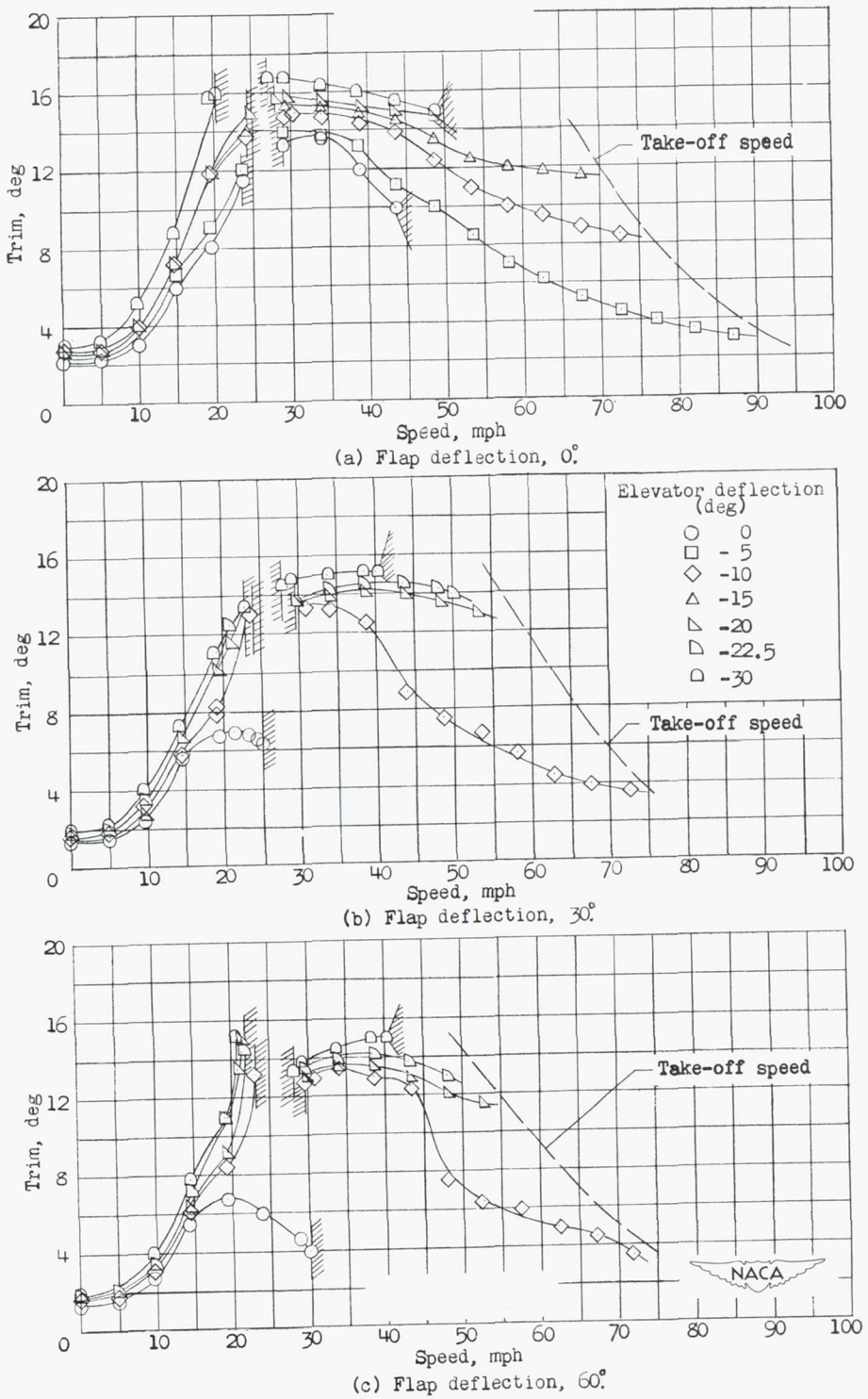


Figure 10.- Variation of trim with speed for the Grumman JRF-5 with hydro-skis. (Values are full size.)

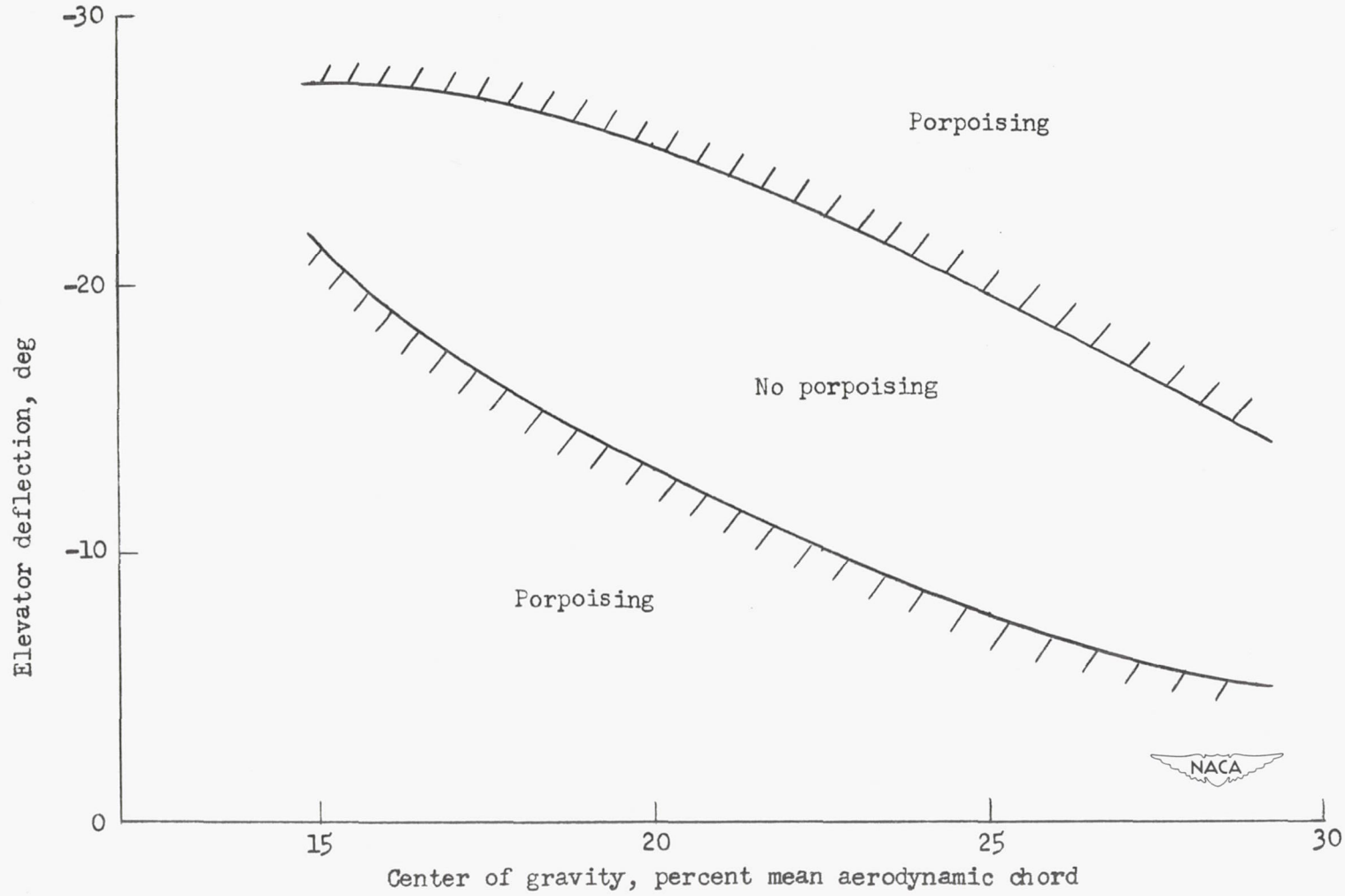


Figure 11.- Center-of-gravity limits of stability for the Grumman JRF-5 with hydro-skis.

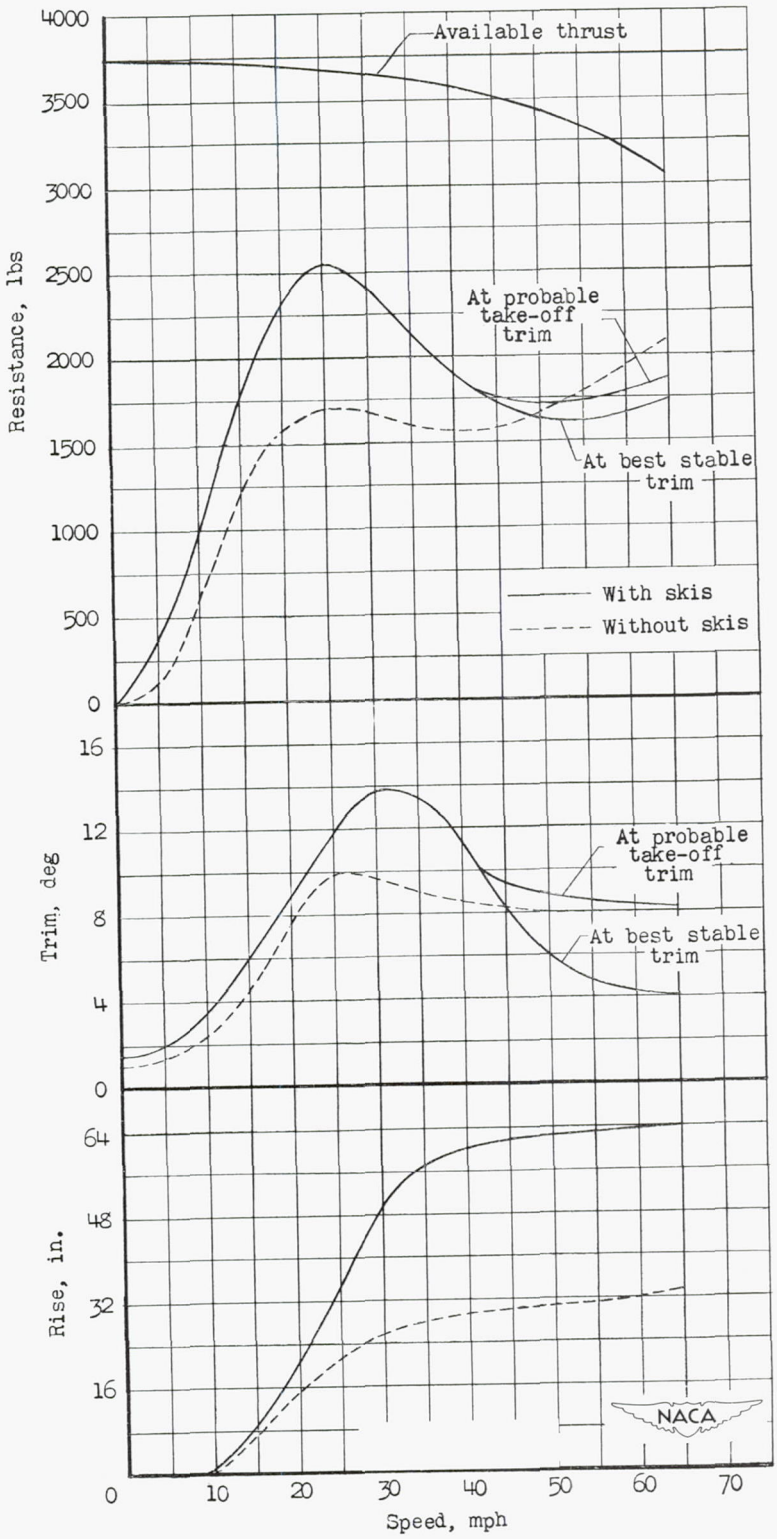
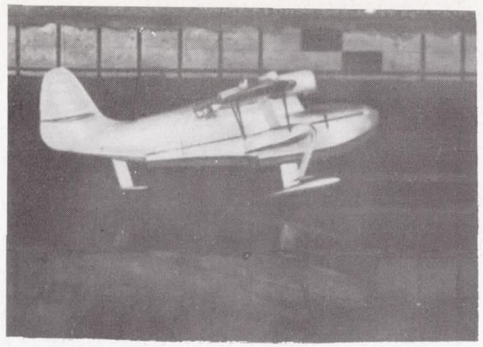


Figure 12.- Resistance, trim, and rise for the Grumman JRF-5 with and without hydro-skis. (Values are full size.)



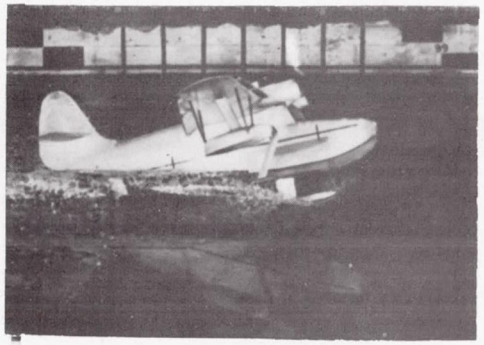
In flight



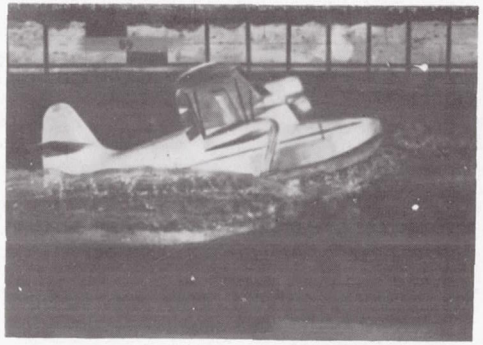
Just after contact



150 feet after contact



450 feet after contact



500 feet after contact



600 feet after contact

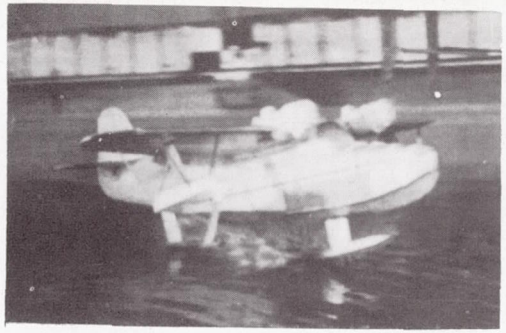
Figure 13.- Sequence photographs of a typical landing run in smooth water at 8° landing trim. (Distances are full size.)

NACA

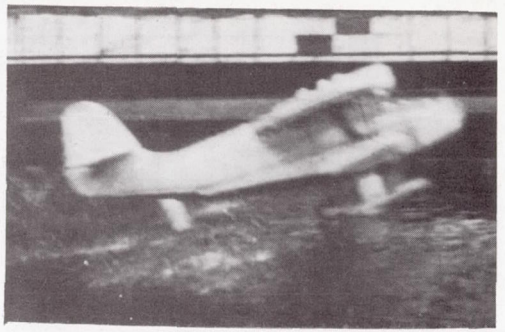
L-63055



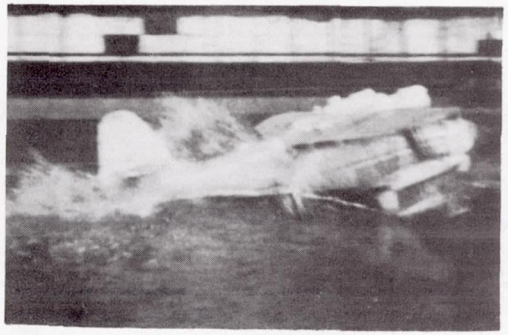
In flight



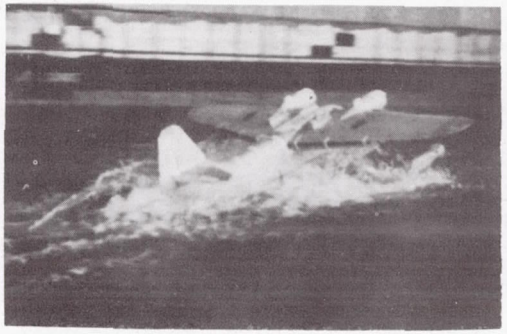
Just after contact



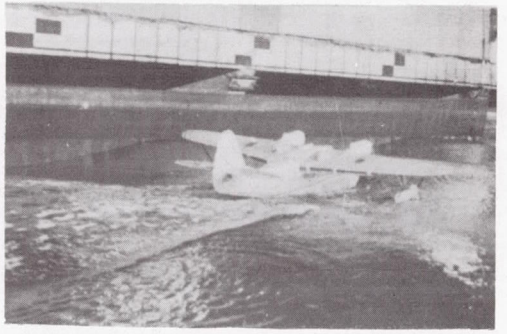
150 feet after contact



450 feet after contact



500 feet after contact



600 feet after contact

Figure 14.- Sequence photographs of a typical landing run in 4- by 120-foot waves at 8° landing trim. (Distances are full size.)

NACA

L-63056

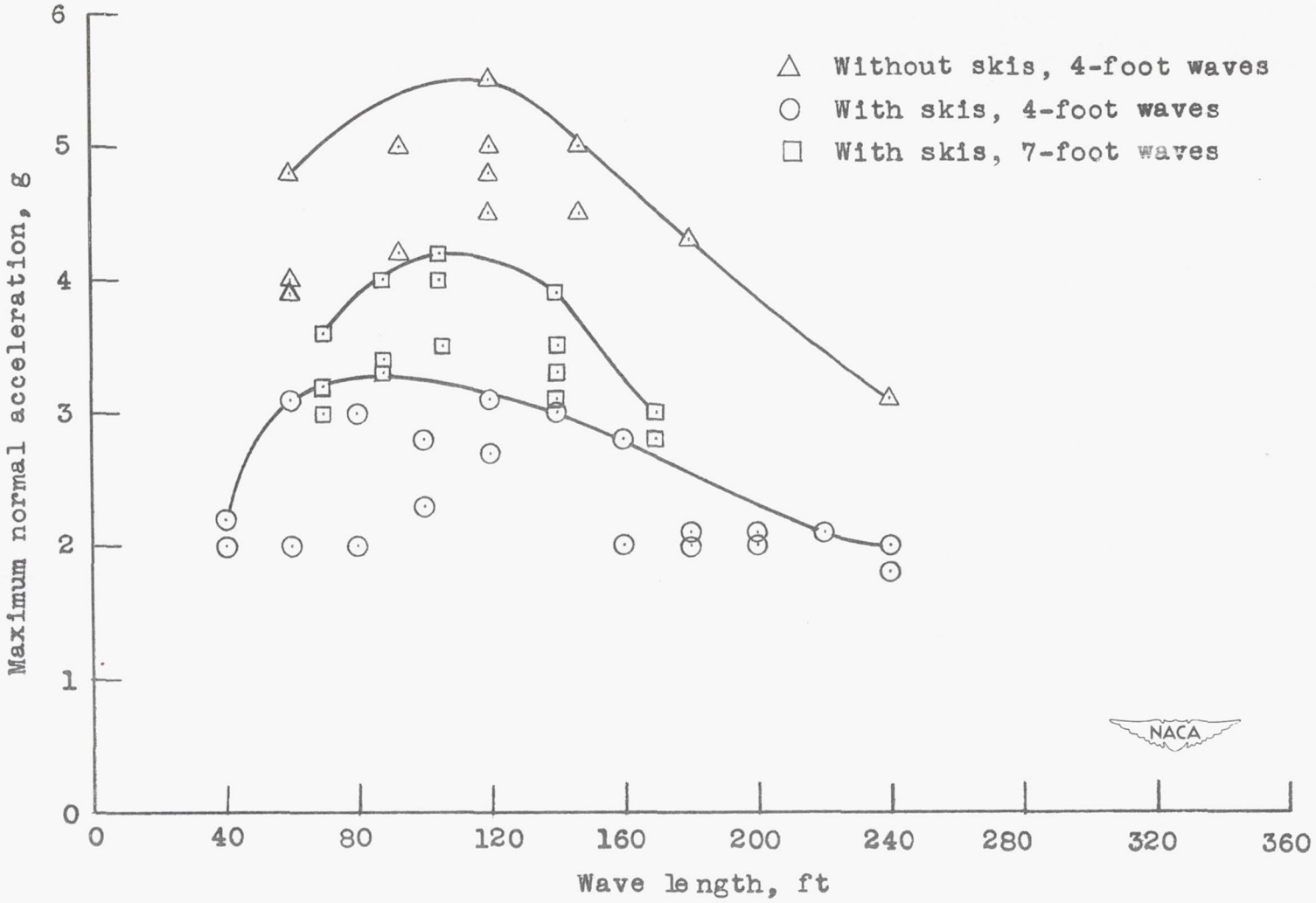
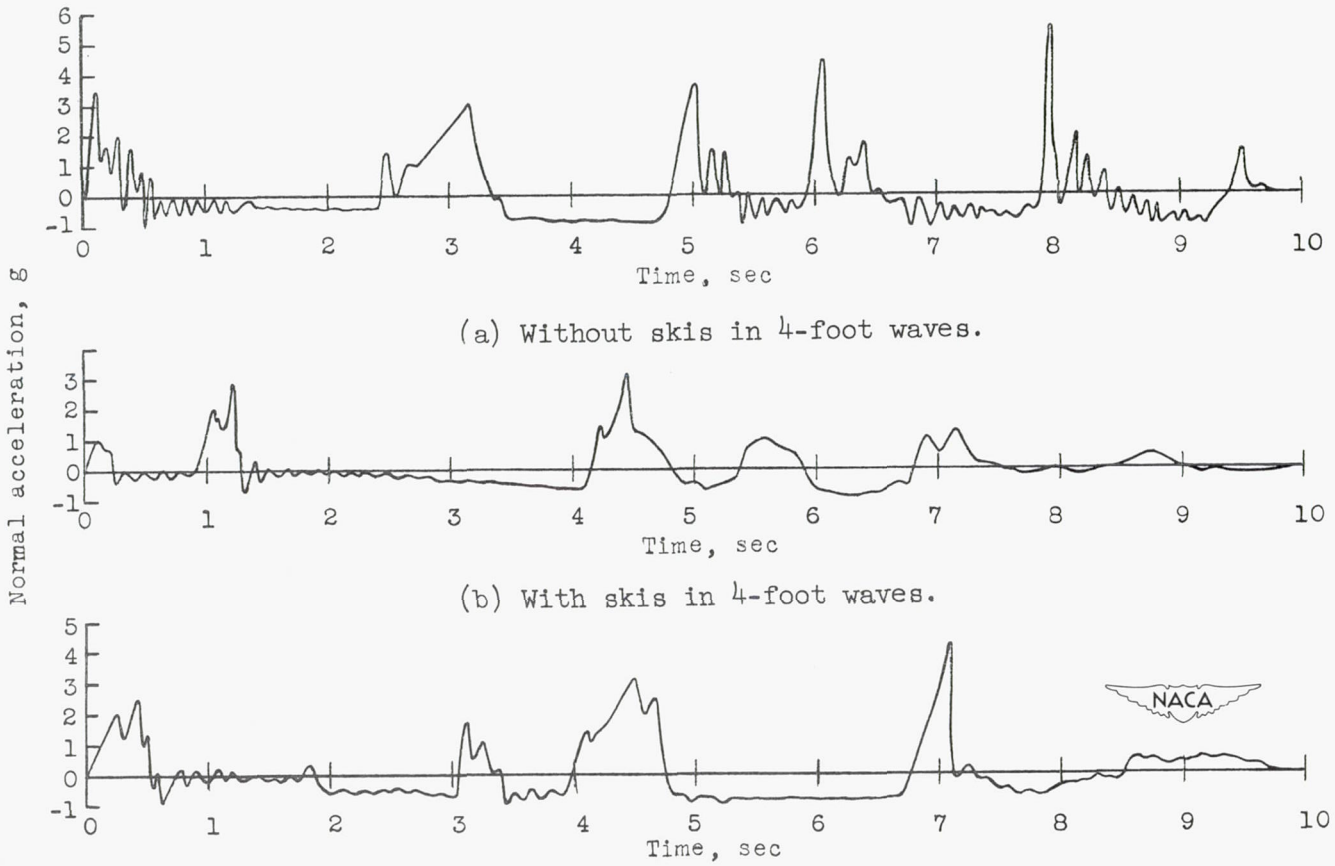


Figure 15.- Variation of maximum normal acceleration with wave length.
(Values are full size.)



(a) Without skis in 4-foot waves.

(b) With skis in 4-foot waves.

(c) With skis in 7-foot waves.

Figure 16.- Normal accelerations encountered during landing runs in rough water. (Values are full size.)